(NASA-TM-82079) A 5.57 HOUR MODULATION OF THE X-RAY FLUX OF 4U1822-37: A NEW MODEL FOR CYG X-3 (NASA) 24 p HC A02/MF A01 CSCL 03B

N81-20001

Unclas
G3/93 18832

NASA

Technical Memorandum 82079

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JANUARY 1981

National Aeronautics and
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A 5.57 HOUR MODULATION OF THE X-RAY FLUX FROM 4U1822-37

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ABSTRACT

We demonstrate that the X-ray flux of 4U1822-37 is modulated with the 5.57 hour period of its optical counterpart. The X-ray light curve is two component with a smooth sinusoidal like 25% semi-amplitude modulation and a 30 minute dip ~ 0.2 in phase following the other minimum. The dip begins at the center of the optical minimum. The X-ray spectrum is a relatively flat power law up to 17 keV, above which it steepens. Iron emission is detected at 6.7 keV with a 4 keV FWHM and an equivalent width of 1100 eV. There is an excess below 2 keV that is consistant with either a 0.25 keV thermal component or 350 eV equivalent width iron L emission. A slight softening of the spectrum is seen during both X-ray minima. The dip is interpreted as the partial occultation of an extended cloud of optically thick highly ionized material surrounding the central X-ray source. Modelling the eclipse gives a system inclination of 70-79^{o} and a spherical cloud radius of 0.2-0.3 R_{o}. We suggest the cloud is a hot corona blown off the surface of an accretion disk. Models for the long term modulation are considered. We compare the properties of this source to those of Cyg X-3 and conclude that they are similar systems.

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I. INTRODUCTION

The optical counterpart of 4U1822-37 is a 16th magnitude blue star whose flux is modulated at a period of 5.57 hours with a color independent peak-to-peak amplitude of one magnitude (Mason et al. 1980; MEL). The duty cycle of the modulation suggests the occultation of an extended region of optical emission (e.g. an accretion disk). We have made observations with the HEAO 1 and Einstein observatories which demonstrate that the X-ray flux of this source is also modulated with the 5.57 hour period. This result is presented here along with high quality X-ray spectra and a discussion of the probable nature of 4U1822-37 and its similarity to Cyg X-3.

II. OBSERVATIONS

The HEAO 1 observatory was primarily a scanning satellite with the ability to stop and point at specific sources. Our results come from two proportional counters of the GSFC A2^{+} experiment (Rothschild et al. 1978):

$^{+}$The A2 experiment on HEAO-1 is a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT, with collaborators at GSFC, CIT, JPL and UCB.

a Medium Energy Detector (MED, 2-15 keV) and a High Energy Detector (HED, 2-60 keV). In contrast, the Einstein Observatory is a stable platform with an X-ray telescope co-aligned with a Monitor Proportional Counter (MPC, 2-20 keV). The Einstein observations were made with a Solid State Spectrometer (SSS, 0.5 to 4.5 keV) at the focal plane (Joyce et al. 1978). HEAO-1 scanning data were available for three five day intervals in 1978 and 1979, six months apart. In addition there was a six hour pointed observation made on 1978 Sept. 25. Two sets of Einstein observations were made in 1979, again six months apart. Table 1 summarizes the measurements.

III. THE 5.57 HOUR MODULATION

Fourier analysis of the HEAO A2 scanning observations indicated each to

be modulated at the optical period, with an overall probability of resulting from random processes of 10^{-6}. The data from HEAO 1 and Einstein were folded using the ephemeris from MEL and comparison of the light curves confirmed the presence of the modulation, revealing in each case a smooth 25% amplitude modulation plus a sharp 30 minute dip about 1 hour after the broad minimum. By cross correlating the light curves we obtain a period from the X-ray data of 0.232110 ± 0.000003 days. This is consistent with the shorter of the two periods given by MEL. In Figure 1 the data from three of our observations are folded about the X-ray period using the optical phase zero ($\phi_o = 0.0$) of JD2444105.668. Also shown is a smoothed photometric B band light curve taken from MEL. We note the following:

a. The X-ray light curve is composed of two features, a smooth modulation that has a broad minimum at $\phi_o \sim 0.85$, plus an additional sharp dip from ϕ_o 0.0 to 0.09.

b. The dip center occurs 0.04 in phase after the optical minimum.

c. The overall structure of the X-ray light curve has remained constant over two years.

d. The amplitude of the optical and X-ray modulations are similar (~ 25% peak to mean).

Because the dip is so distinctive it is an excellent reference point for future X-ray measurements of the 5.57 hour period. Thus in Table 1 we give epochs for the X-ray light curves referenced to the center of this feature, as defined by the A2 pointed observation. There does not appear to be any phase drift $\Delta\phi$ between the dip and broad minimum > 0.07 yr^{-1}. Because of incomplete phase coverage for each observation we cannot define an unbiased epoch for each component of the modulation. We note that all these measurements were separated by multiples of six months, so that a phase drift which was coincidentally one cycle per six months would be undetectable.

The data were searched for regular pulsations with periods between 160 ms

and 30 minutes. None were found with an upper limit of ~ 5%. A search for evidence of irregular variability on timescales between 80 ms and several minutes, using an autocorrelation analysis, similarly yielded an upper limit of a few percent. The average intensity of the source was constant to within 10% over the two years of observations.

IV. SPECTRUM

The MED data summed over the pointed observation were fit to standard spectral models, including iron K emission at ~ 6.7 keV and low energy absorption. Only a power law model yielded a reasonable fit. The same was true of the HED data, although a high energy cutoff at 17 keV was also necessary to give an acceptable χ^2. The spectral parameters derived are given in Table 2 and the photon spectrum shown in Figure 2. The iron line width of 4 keV is extremely broad. The equivalent width (EW) is 1090 ± 320 eV (90% confidence). Very little spectral variation is associated with the 5.57 hour modulation. This is illustrated in Figure 3 where the ratio between PHA data for each detector taken during the dip (ϕ_o 0.03 to 0.07), the maximum (ϕ_o 0.30 to 0.43) and the broad minimum (ϕ_o 0.61 to 0.93) of the modulation are shown. An increase in absorption during the dip or the low intervals would be reflected as a decrease in the ratio at lower energies, but the data suggest, on the contrary, a slight softening during the periods of reduced X-ray emission. The spectral parameters for each of the three phase intervals also reflect this tendency, with a one sigma decrease in the measured absorption from 8.2×10^{21} to 4.2×10^{21} and 5.9×10^{21} H atoms cm^{-2} for the dip and low intervals respectively. The data would allow a variation of as much as 80% in the EW of the iron line across the modulation (see Figure 3).

The SSS spectrum was summed over each of the two observations. Again only a power law model yielded a reasonable fit to the data. However, as shown in Table 2 and Figure 4 the χ^2 for a power law plus absorption model was formally unacceptable. The residuals indicated an excess below 2 keV (Fig. 4)

that could be modelled either as an additional low temperature component or as an emission line at 0.8 keV. For the former possibility either a 0.25 keV thermal or a 0.16 keV blackbody gave an acceptable χ^2. Alternatively, because the SSS is not sensitive below 0.5 keV, a broad 350 eV EW line at 0.8 keV gives a similar result (Table 2).

Comparison of the photon index and absorption from each detector show that as the effective bandpass of the detector decreases from the HED to the SSS, both the index and absorption decrease. This suggests that a single power law is not an adequate representation of the overall spectrum and that the continuum turns over at low energies. This would account for the poorness of the MED fit. The hydrogen column density measured by the SSS of $\sim 2 \times 10^{21}$ H atoms cm^{-2} should therefore be our most reliable estimate. The luminosity in the 0.5 to 50 keV band is $2.3 \times 10^{35} \times d^2$ ergs s^{-1} kpc^{-2}, where d is the distance to the source. Because the source is off the galactic plane ($b = 11^o$), d is not well determined at present with only a lower limit of 0.6 kpc (MEL). The unabsorbed luminosity of the low temperature component is convolved with the uncertainty in the absorption. The observed luminosity is 0.18×10^{-10} ergs cm^{-2} s^{-1} ($2 \times 10^{33} \times d^2$ ergs s^{-1} kpc^{-2}), while the unabsorbed luminosity is a factor 10 to 100 greater depending on the assumed interstellar absorption.

V. THE MODEL

This system is probably a 5.57 hour dwarf binary system, with the x-ray emission caused by matter accreting onto a degenerate star from a relatively normal companion. By assuming the companion is a main sequence star filling its Roche lobe, MEL constrained it to be a late type dwarf with radius 0.5 - 0.7 R_o and mass 0.4 - 0.8 M_o. For $i \sim 90^o$, an X-ray eclipse of the order of 0.02 to 0.03 days would be expected, which is comparable with the 0.019 day duration of the X-ray dip. This, combined with the fact that the optical minimum occurs within 0.05 phase of the X-ray dip, suggests it is associated

with an X-ray occultation, but of a type quite different from eclipses previously observed from X-ray binaries. The flux reduction is only 50% and both the egress and probably the ingress (we did not observed a complete ingress) are not sharp, but together take up 2/3 of the eclipse. Three possible effects could cause this: 1) the eclipse is grazing; 2) the system is immersed in a cloud/shell of material; 3) the X-ray source is extended with dimensions comparable to that of the companion star.

The first can be eliminated from the lack of a substantial increase in photo-electric absorption during the dip. The second model has been widely discussed in the literature with reference to Cyg X-3 (see Parsignault et al. 1977 and refs. therein). Hertz, Joss and Rappaport (1978) have simulated it for both a cloud and a shell of material surrounding the system and their results for a shell with Compton scattering optical depths of 1 or 2 give eclipses similar to those we observe from 4U1822-37. Elsner et al. (1980) and Ghosh et al. (1980) have extended this to eccentric orbits and their work can probably be used to qualititatively reproduce the light curve of 4U1822-37. However, both the lack of any substantial absorption or any variation in absorption across the light curve pose major problems to the application of this model. An optical depth of unity requires an $\dot{M}$ of 2×10^{20} gm s^{-1} from the companion, with an equivalent column density of $\sim 10^{24}$ H atoms cm^{-2}, three orders of magnitude above the observed value. The cloud may be completely ionized from photoionization by the central X-ray source, but the material in the companions shadow will still be relatively cool and should cause a substantial increase in absorption during eclipse. Alternatively, it is plausable that the cloud is a hot stellar wind blown off the face of the companion by the X-ray source. The maximum wind that can be "self excited" from the companion is given by $\dot{M} \simeq 2.8 \times 10^{-19}\ L_x$ gm s^{-1} (Basko et al. 1977), so that an L_x of 10^{38} erg s^{-1} yields an $\dot{M}$ of 3×10^{19} gm s^{-1}, which is at least one order of magnitude below that required. The alternative of a shell

rather than a cloud surrounding the system might circumvent some of these difficulties, but we would then have to invoke an ad hoc energy source to keep it ionized.

These problems have lead us to consider a third model, wherein we reduce the size of the optically thick scattering cloud to less than the separation of the binary system and center it on the X-ray source, rather than its companion. The cloud will then act as a sort of lamp shade and make the X-ray source appear extended. There should be no spectral change associated with the eclipse because it is purely an occultation of the cloud by the companion. The shape and duration of the eclipse, from simple geometry, can constrain the size of the cloud and the inclination of the system, when a range of sizes for the companion (given earlier from MEL), a mass of 1.5 M_o for the compact star and a cloud geometry are assumed. To see how model dependent the inclination and cloud size are, we have considered two extremes of cloud geometry: a sphere and a thin disk with, in both cases, the source completely immersed in the cloud, uniform brightness and no correction for limb darkening. The sphere gave a best fit to the eclipse for a range of inclination from 69 to 76^o and a cloud radius R_c of 0.20 to 0.30 R_o, the principle uncertainty being in the size of the companion. Figure 5 shows the HEAO A-2 pointed data with the best fit eclipse drawn through it. A disk model with a thickness of 0.1 R_o gave the same range of inclination angle as the sphere with a radius of 0.34 to 0.38 R_o. As can be seen in Figure 5, the predicted shape of the eclipse is similar for both models. While the true cloud geometry is probably much more complicated than either of these two models, we shall assume, for the sake of simplicity, that the cloud is spherical.

The optical depth τ of the cloud must be greater than 1 ($n_e \sigma_T R_c \geq 1$) and assuming a homogeneous cloud with radius 0.25 R_o gives a density $n_e = 7 \times 10^{13} \times \tau\ cm^{-3}$. The original spectrum from the central X-ray source will be

modified by Compton interactions with the surrounding medium. The output spectrum will be a function not only of the optical depth of the cloud but also of the relative temperature of the central X-ray source to that of the surrounding cloud. When the temperature of the central source is much hotter than that of the cloud the spectrum will have a high energy cutoff at an energy of m_ec^2/τ^2 (Illarionov and Syunyaev 1972; Ross, Weaver and McCray 1978; Sunyaev and Titarchuk 1980). This is precisely what we see from 4U1822-37 and the break energy of 17 keV gives an optical depth of ~ 6. Combining this with the above density estimate gives $n_e \simeq 3.8 \times 10^{14}$ cm^{-3}. The observed photo-electric absorption of ~ 2×10^{21} H atoms cm^{-2} means the cloud must be fully ionized. If this state is maintained by photo-ionization by the central source then $\tau L_x/n_eR_c{}^2 > 10^3$ (Ross 1979), giving $L_x \gtrsim 10^{37}$ ergs s^{-1} ($d \gtrsim 9$ kpc). The cloud will be hot and it is interesting to consider the possibility that the low energy excess seen by the SSS may be the resulting thermal emission. The temperature is 3×10^6 K with an emission measure ($n_e{}^2R_c{}^3$) of $9 \times 10^{57} \times d^2$ cm^{-3} kpc^{-2}, which for a 0.25 R_o cloud gives $n_e = 3 \times 10^{13} \times d$ cm^{-3} kpc^{-1}. Given the 50% uncertainty in the emission measure this is quite compatible with the first density estimate for ($d \simeq 10$ kpc). These simple arguments suggest that the source must be very luminous (> 10^{37} ergs s^{-1}). If this is the case then its ℓ and b of 356° and 11° respectively, mean that for a distance of 10 kpc it is 2 kpc off the galactic plane.

What is the origin of the cloud? The optical minimum suggests the obscuration of a large region of cool material which is probably an accretion disk illuminated by the central X-ray source. The cloud may be a corona or hot wind above and below the central region of the disk and is the result of material evaporated from its surface by the X-ray source (Shakura and Sunyaev 1973). Such a scenario is thought to account for the X-ray emission seen from Her X-1 during the off part of the 35 day cycle (Jones and Foreman 1976; Becker et al. 1977; Pravdo et al. 1979; Bai 1980). Because of the uncertainty

in the luminosity of 4U1822-37 we can only say that the flux is comparable to or greater than the low state flux from Her X-1. If in 4U1822-37 the cloud does not completely surround the source, then while the intrinsic luminosity is ~ 10^{37} erg s^{-1}, we may observe a scattered flux up to a factor 100 lower, thus bringing the distance down to ~ 1 kpc. The accretion disk radius will be many times larger than that of the scattering cloud and it will occult part of the cloud, with the amount hidden a function of the system inclination, the accretion disk thickness and the cloud geometry. We have considered the effects of this on our modelling of the eclipse. In the case of a spherical cloud at inclinations $\lesssim 80^{\circ}$, the bottom half will be completely occulted by the accretion disk and it is more appropriate to use a hemisphere for the cloud geometry. This gives a corrected range of inclination of 72-79°. For a disk shaped cloud the correction is dependent on the thickness of the cloud and for 0.1 R_o thickness, the new range of inclination is 70-78°. In both cases the estimates for the cloud radii remain unchanged.

The long term sinusoidal modulation probably arises from an asymmetry in the system that is fixed relative to the companion and the X-ray source. Independent evidence for this is given from the fact that the optical minimum occurs 0.04 in phase before the center of the X-ray occultation i.e. the leading edge of the disk is brighter. Two ways of creating this asymmetry are possible.

Firstly, the degenerate star may be phase locked to its companion, i.e. it is a pulsar rotating extremely slowly. This situation would be similar to the magnetically locked accreting white dwarf model for AM Her (see Joss, Katz and Rappaport 1979 and refs therein). However, both the X-ray and optical properties of 4U1822-37 bear little, if any, resemblance to the AM Her stars. The simplest variant is to exchange the white dwarf for a neutron star. Joss, Katz and Rappaport (1979) have considered such a possibility for Cyg X-3 and conclude that it is feasible, so long as the companion star has a

large enough magnetic moment to provide sufficient magnetostatic interaction to overcome the tendancy for the neutron star to spin up. If the spin axis of the neutron star is co-aligned with the orbital axis, but the magnetic axis is not, then the asymmetry arises naturally from accretion onto only one pole, because the neutron star itself will occult 50% of the X-ray emission from the accreting pole. Because the X-ray maximum occurs at $\phi_o \sim 0.4$, the active pole of the neutron star must be pointed in the direction of its orbital velocity vector, thus illuminating the disks leading edge and accounting for the earlier optical minimum. A further perturbation to the long term modulation will be caused by the fact that the X-ray emission from the neutron star pole is probably itself asymmetric. The surrounding cloud will smooth out any underlying self-eclipse and beaming of the X-ray flux. Calculation of the residual modulation is non-trivial and dependent on the assumed cloud geometry. However, the Monte Carlo simulations of Hertz, Joss and Rappaport (1978), for Compton scattering in a $\tau \sim 5$ shell surrounding an eclipsing binary, suggest there will probably be sufficient residual amplitude to account for the observed modulation. We note the possibility that the magnetic phase locking will involve large magnetic fields that could prevent the formation of a disk and potentially pose a problem for certain aspects of this model.

Alternatively the sinusoidal modulation could be caused by a bulge at the edge of the accretion disk partially occulting the cloud. At the point where the inflowing material joins the accretion disk there may be an increase in the disk thickness (e.g. Lubow and Shu 1976). This point would then be fixed relative to the companion and would occult different amounts of the corona, depending on the orbital phase. The fact that the optical minimum occurs slightly early indicates that the bulge also partially eclipses the more extended optical emission from the disk and, as suggested by MEL, this partial eclipse is responsible for the gradual decline in optical flux from $\phi_o \sim 0.7$

to 0.9.

VI. THE IRON LINE EMISSION

If the Fe K line emission is from fluorescence of relatively cool material it may occur at any of the following places: the neutron star surface, the Alfven surface, the corona, the surface of the companion and the disk surface. The first possibility is ruled out because the line will be gravitationally red shifted by ~ 1 keV, inconsistent with the observed line energy. The second is unlikely because the line EW scales inversely with the radius of the Alfven surface and it is not possible to produce more than a few hundred eV of iron emission, without making the Alfven radius less than a neutron star radius (see White and Pravdo 1979). The corona is also unlikely to be a large source of line emission because, as already mentioned, most of the iron is fully ionized. The companion star will see only a very small percentage of the output flux and again will give a negligible EW. The disk on the other hand, will intercept a large fraction of the scattered X-ray flux, because of the presence of the optically thick corona above it. Normally the disk would subtend a very small solid angle to the central source and result in little fluorescence. However, an optically thick corona above the disk redistributes the original X-ray flux and causes the disk to intercept 50% of the scattered emission. From Bai (1980) we have

$$EW = \frac{3.4 \times 10^{-2} \cdot \Omega \cdot \int_{7.1}^{\infty} q(E).(E/7.1)^{-1.4}\, dE}{q(E = 6.4)}$$

A solid angle Ω of 2π yields an EW of ~ 900 eV, quite consistant with the observed value. The resulting line emission is then scattered back through the cloud, causing the observed line to be very broad. Because the disk intercepts such a large fraction of the scattered emission, the presence of the hot corona may set up a positive feedback situation that feeds and maintains the corona (a 'self excited corona'?).

While the hypothesis that the low energy excess is from the thermal emission of the cloud is attractive, we have also considered the possibility that it could be caused by line emission from iron L at 0.8 keV. The fluorescence yield (FY) of iron L is only ~ 1% of that from the K shell (Bambynek et al. 1972). Additional L shell vacancies caused by K shell vacancies being filled and the more efficient photo-ionization efficiency at 0.8 keV give an effective yield ~ 6%. The spectrum is relatively flat below 17 keV so from the ratio of the EWs we find the L emission to be 34 ± 20% (2 sigma) of the K, much in excess of that expected. The poor FY for the transitions to the L shell is because most of them give off Auger electrons. However if the M shell is almost completely ionized then the Auger effect becomes less efficient and the FY will increase. Thus, if there is L shell emission at this level it suggests an abundance of ion around Fe^{15}, which in turn gives a temperature for the surface of the disk of ~ 10^5K (Hatchett, Buff and McCray 1976).

VII. A CYG X-3 CLASS

Cyg X-3 has remained an enigma since its discovery in 1972, apparently being a unique phenomenon. Apart from the modulation periods being similar (4.8 vs. 5.6 hours) there are several other features that suggest 4U1822-37 and Cyg X-3 are fundamentally similar.

a. The two light curves are very similar both in shape, stability and depth of modulation (e.g. Elsner et al. 1980). The lack of an eclipse (dip) from Cyg X-3 may be caused by a lower inclination.

b. In both cases there is no phase dependent absorption (Blisset, Mason and Culhane 1980; White et al. 1979).

c. The low state spectrum of Cyg X-3 is virtually identical to that of 4U1822-37, being a power law with a high energy cutoff and an additional low temperature component (White et al. 1979; Becker et al. 1978).

d. Both have very large broad iron lines at 6.7 keV (e.g. Becker et al.

1978).

e. The distance and luminosity of Cyg X-3 are well established at 10 kpc and 10^{38} erg s^{-1}, respectively (Serlemitsos et al. 1975). The model we discuss for 4U1822-37 infers this source is also > 10^{37} ergs s^{-1}.

Models for Cyg X-3 have concentrated on the whole system being immersed in a cloud/shell of material centered on the companion to explain the origin of the 4.8 hour modulation (see earlier discussion). However, the aforementioned similarities suggest that the model we have proposed for 4U1822-37, where the cloud is centered on the X-ray source and is smaller than the binary separation, may be a viable alternative for Cyg X-3. Because Cyg X-3 is in a region of high optical extinction it cannot be observed between the near infared and X-ray bands. Thus, further observations of 4U1822-37 at all wavebands could also provide a much better insight into this class of X-ray source.

We thank Keith Mason, Dick McCray, Pranab Ghosh and Andy Fabian for discussions and an anonomous referee for some useful comments.

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TABLE 1. THE OBSERVATIONS AND TIMES OF MID ECLIPSE

START	DURATION (DAYS)	SATELLITE	EPOCH* - JD2440000+
1977 Sept 27	5	HEAO A2 SCAN	3413.5265 ± 0.0046
1978 April 6	5	HEAO A2 SCAN	3591.5520 ± 0.0046
1978 Sept 25.3	0.25	HEAO A2 POINT	3776.5450 ± 0.0023
1978 Sept 27	5	HEAO A2 SCAN	3778.4058 ± 0.0046
1979 April 6.9	0.2	EINSTEIN	3969.4240 ± 0.0069
1979 Sept 17.8	0.9	EINSTEIN	4133.5253 ± 0.0034

*As defined by the fits to the eclipse seen during the HEAO A2 point (Figure 5). The epochs are obtained from cross correlating the whole light curve.

TABLE 2 - SPECTRAL FITS

	HED	MED	SSS
Norm	0.12(0.01)	0.043(0.004)	0.023(0.003)
$\alpha + 1$	1.35(0.05)	1.15(0.05)	0.79(0.05)
N_H (H cm^{-2})	3.5×10^{22} (1.5)	6.1×10^{21} (2.5)	8.4×10^{20} (5.0)
E_{cutoff}(keV)	17.4(0.5)	---	---
E_{Fold} (keV)	11.9(1.5)	---	---
χ^2_r	1.3	2.3	3.4

SSS - MULTICOMPONENT FITS

	PL+Th	PL+BB	PL+Line
Norm 1	0.025(0.003)	0.024(0.003)	0.021(0.003)
$\alpha + 1$	0.76(0.05)	0.74(0.05)	0.64(0.05)
N_H (H cm^{-2})	3.4×10^{21} (1.2)	2.5×10^{21} (0.9)	9.9×10^{20} (5.0)
Norm 2	1.8 ± 0.9	21.1(9.0)	---
kT(keV)	0.25 ± 0.05	0.15(0.04)	---
χ^2_r	1.5	1.5	1.6

LINE PARAMETERS

	MED	HED	SSS
Line strength (ph $cm^{-2} s^{-1}$)	5.5×10^{-3}(1.3)	$2.2 \times 10^{-3}(^{-1.4}_{+2.5})$	5.4×10^{-3}(2.9)
Line FWHM (keV)	4.4(2.0)	3.2(2.0)	0.64(0.20)
Line energy (keV)	6.6(0.2)	6.9(0.5)	0.78(0.08)
EW(eV)	1090(320)	$350(^{-200}_{+400})$	$366(^{-200}_{+500})$

FIGURE CAPTIONS

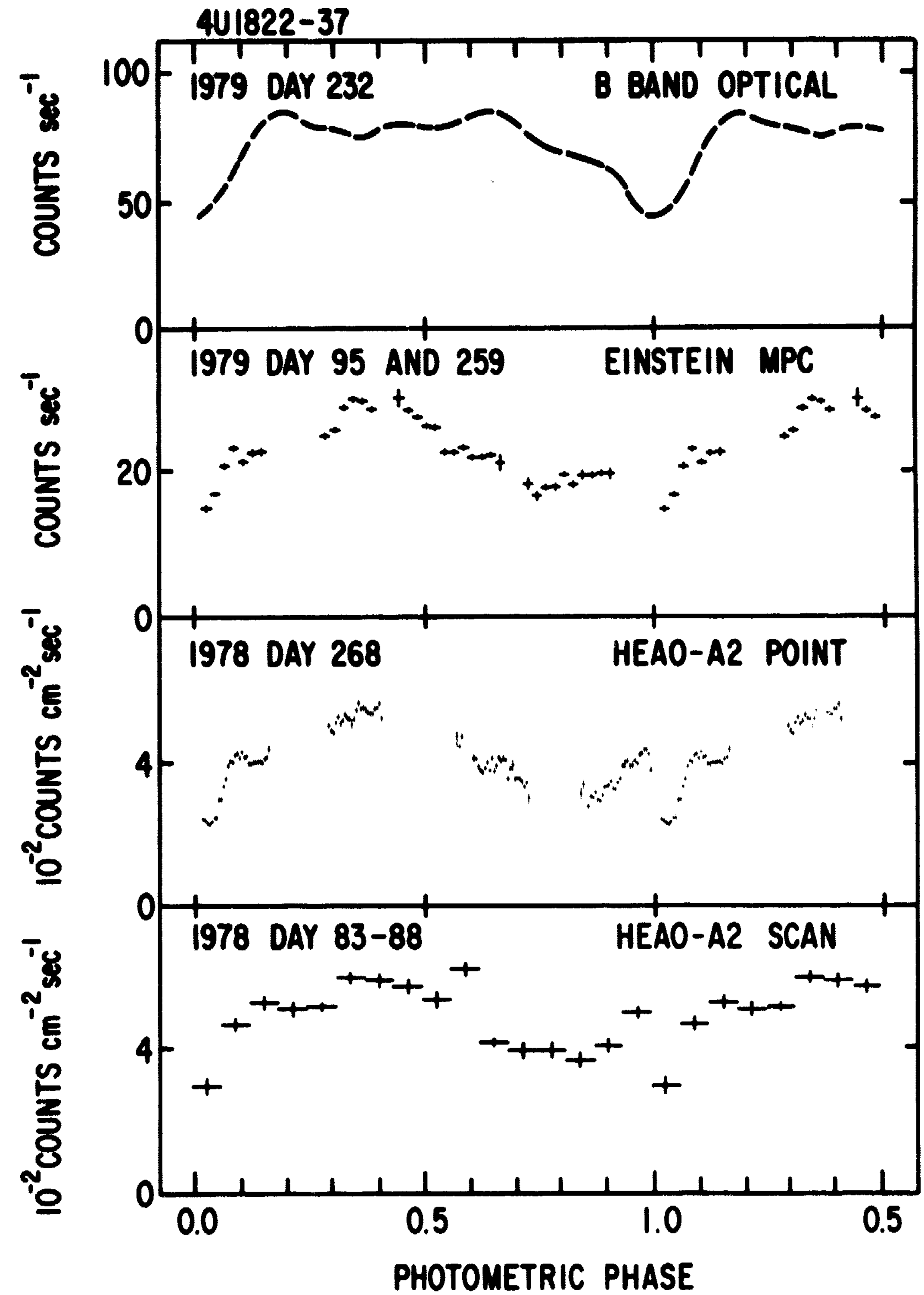
Figure 1 - The data from three observations folded at the X-ray period of 0.23211 days using the epoch of optical minimum from MEL. Also given is the B band light curve from Figure 3 of MEL.

Figure 2 - The photon spectrum from the MED and HED detectors after taking out the detector response, assuming the best fit spectrum for each in Table 2.

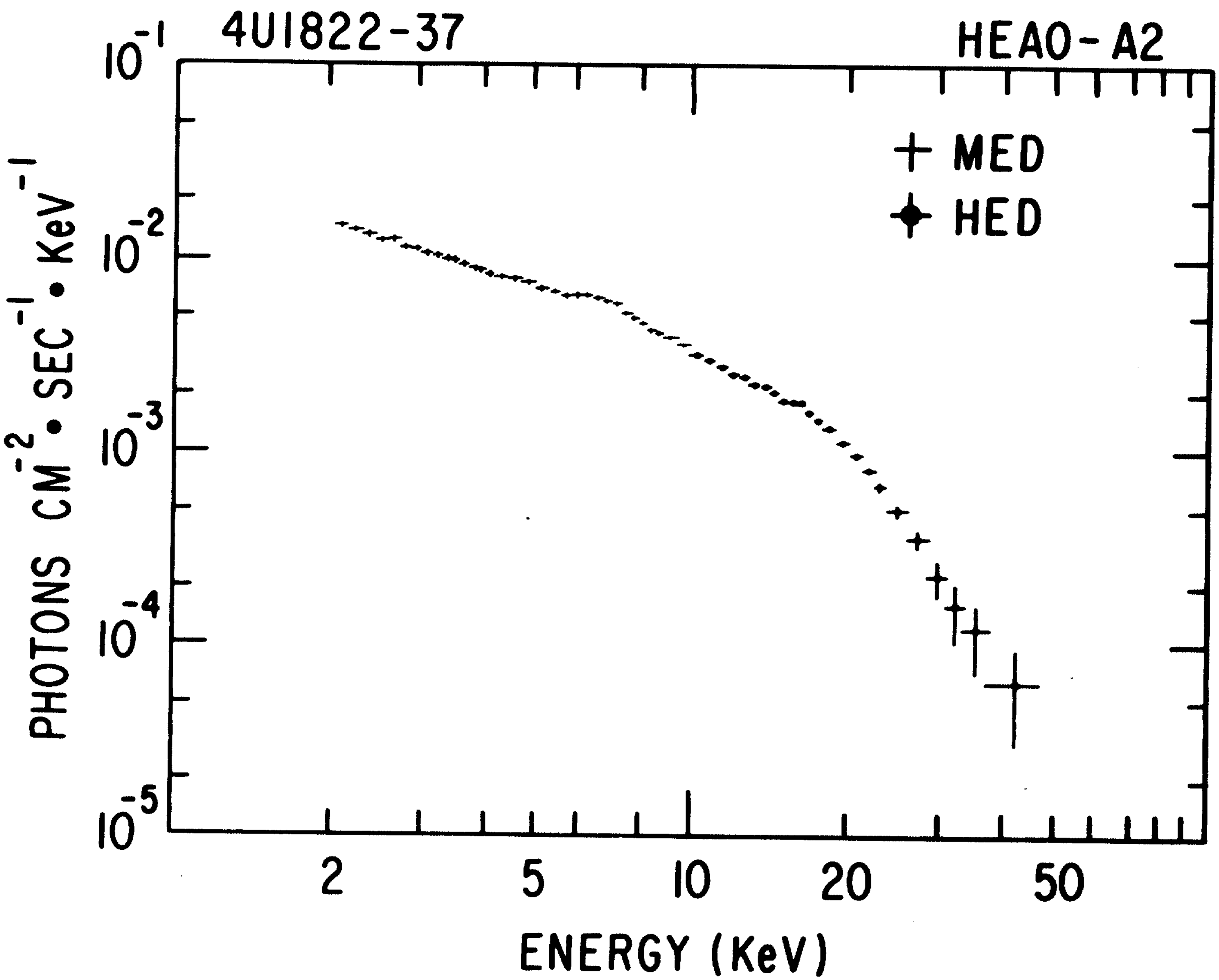
Figure 3 - The ratio of the PHA data from three intervals defined as follows: dip (0.03 to 0.07); high (0.30 to 0.43), low (0.61 to 0.93). The total count rates for each interval were normalized to 1 ct s^{-1}, giving an average ratio of one.

Figure 4 - The SSS data from the second Einstein observation. From top to bottom - The PHA data with the best fit single component model; the PHA data with the best fit power law plus thermal model (given in Table 2); and the spectrum invented using the best fit parameters. The dashed line indicates the best fit power law.

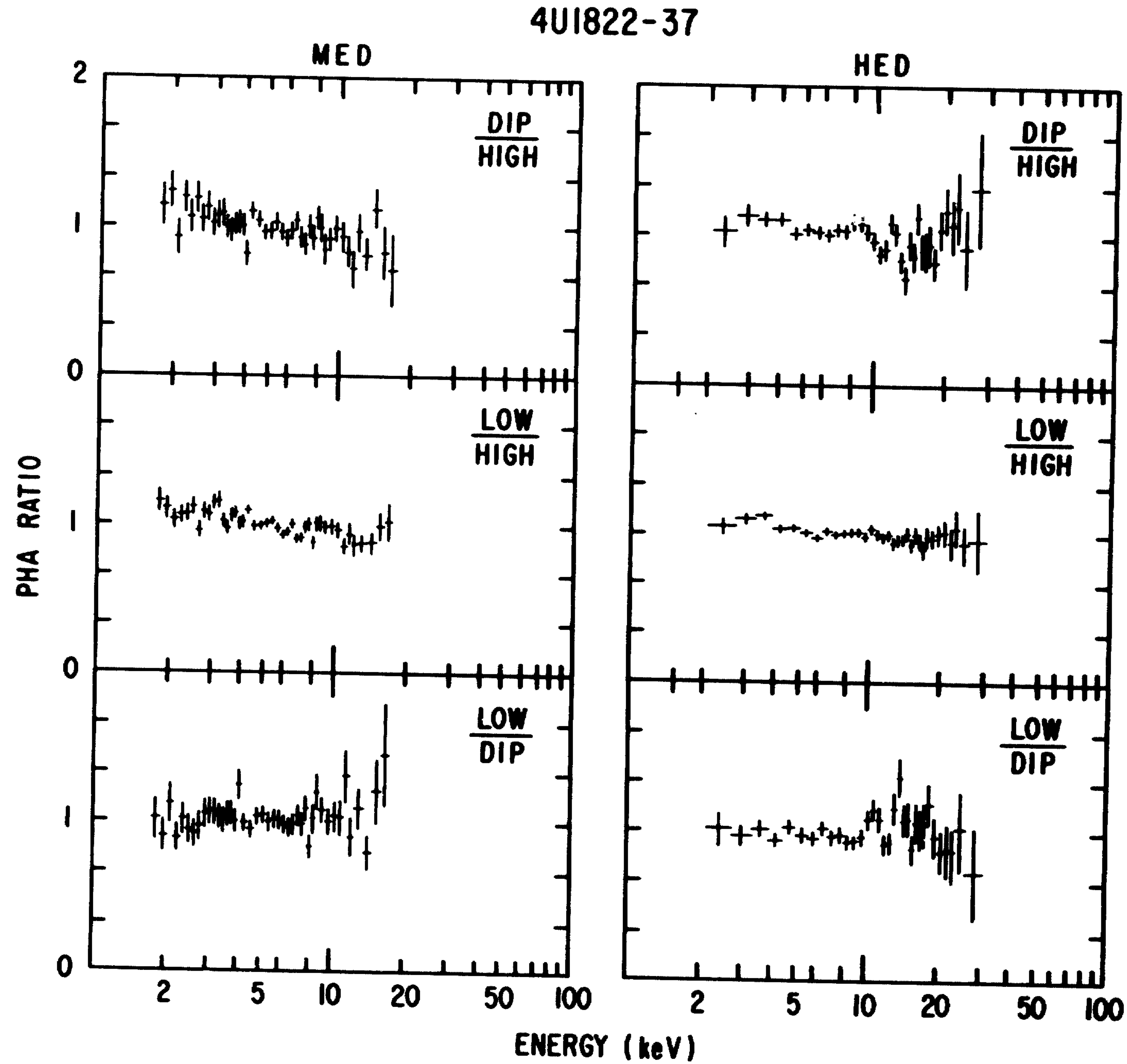
Figure 5 - The data from the HEAO A-2 point gives with a time resolution of 50s. The best fit eclipses for a sphere and disk of material surrounding the X-ray source are shown. The phases are given defining the center of the X-ray dip as phase zero.

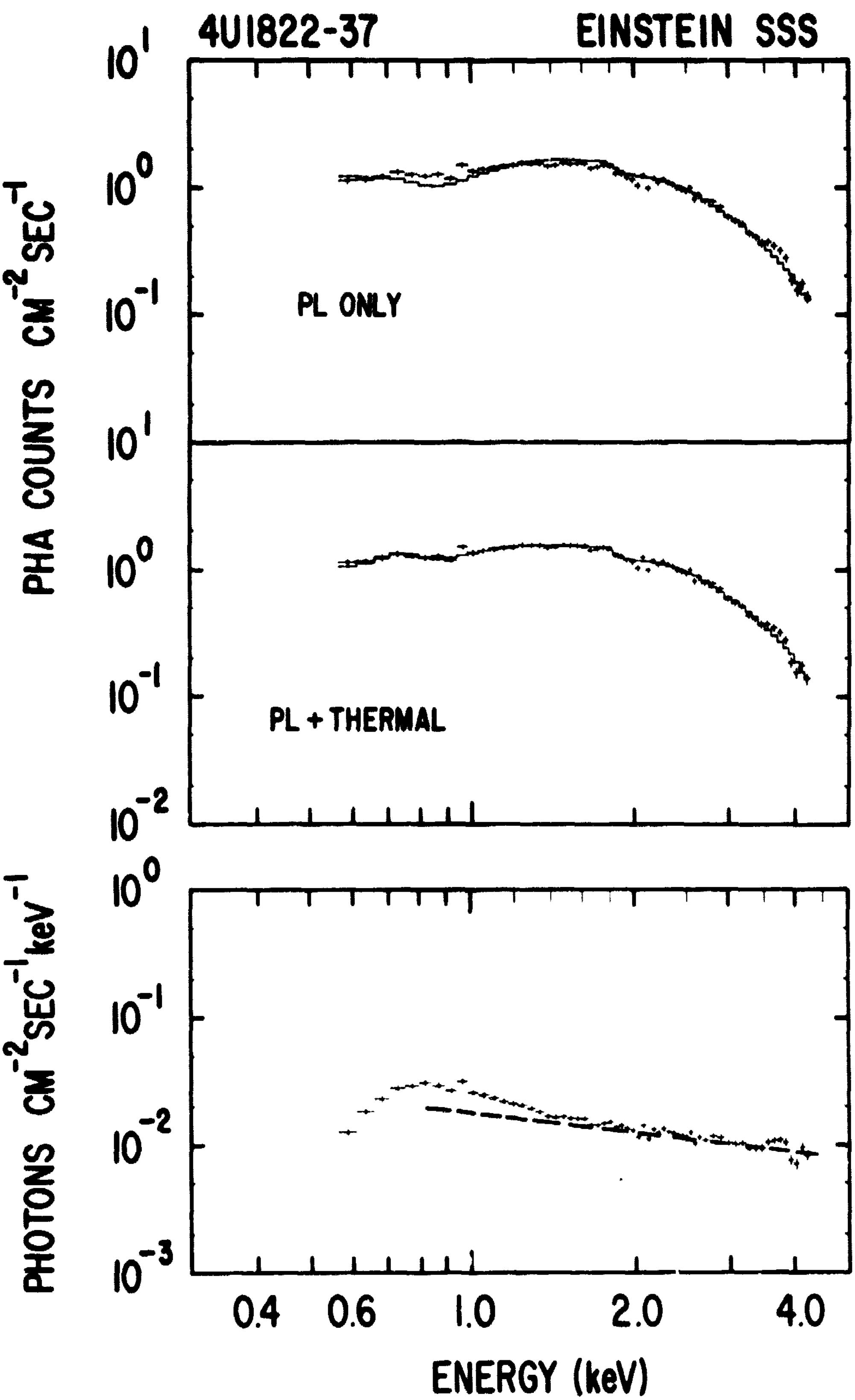


4U1822-37
1979 DAY 232
B BAND OPTICAL
COUNTS sec^{-1}
100
50
0
1979 DAY 95 AND 259
EINSTEIN MPC
COUNTS sec^{-1}
20
0
1978 DAY 268
HEAO-A2 POINT
10^{-2}COUNTS cm^{-2}sec^{-1}
4
0
1978 DAY 83-88
HEAO-A2 SCAN
10^{-2}COUNTS cm^{-2}sec^{-1}
4
0
0.0
0.5
1.0
0.5
PHOTOMETRIC PHASE

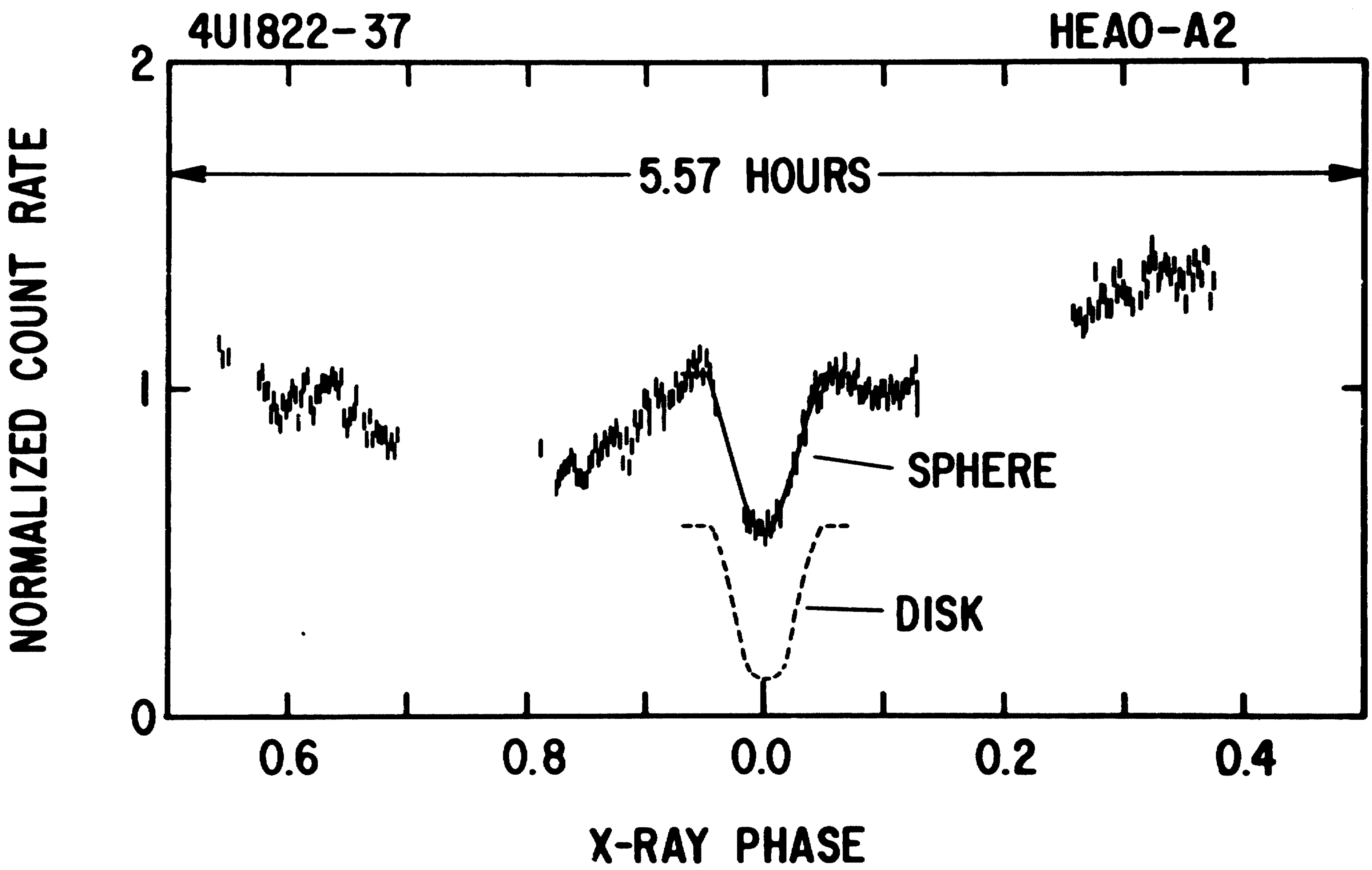


4U1822-37
HEAO-A2
MED
HED
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
PHOTONS CM^{-2} • SEC^{-1} • KeV^{-1}
2
5
10
20
50
ENERGY (KeV)


4U1822-37
MED
HED
DIP/HIGH
LOW/HIGH
LOW/DIP
PHA RATIO
0
1
2
2
5
10
20
50
100
ENERGY (keV)



4U1822-37
EINSTEIN SSS
PHA COUNTS CM^{-2}SEC^{-1}
PL ONLY
PL + THERMAL
PHOTONS CM^{-2}SEC^{-1}keV^{-1}
0.4
0.6
1.0
2.0
4.0
ENERGY (keV)


4U1822-37
HEAO-A2
5.57 HOURS
SPHERE
DISK
NORMALIZED COUNT RATE
X-RAY PHASE
2
1
0
0.6
0.8
0.0
0.2
0.4

ADDRESSES

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